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UNITED STATES NAVAL ENGINEERING EXPERIMENT STATION

REPORT

WEAR CHARACTERISTICS OF STERN TUBE AND STRUT BEARING AND JOURNAL MATERIALS

- NS-633-001 -

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ANNAPOLIS, MARYLAND

ABSTRACT

This is the first report on the progress of an investigation to determine the wear characteristics of stern tube and strut bearing and journal materials. An Amsler wear testing machine was adapted to produce the desired conditions of sand contaminated water lubrication. Nine journal materials, including brasses, bronzes, monel, and stainless steel were run against four bearing materials, each combination being tested for one hour. The bearing materials were Buna-N synthetic rubber, Lignum Vitae wood, and two phenolicimpregnated, laminated plastics.

The results indicate that there is no "best" journal material for all stern tube and strut bearing applications. The choice of a journal material must be based on both journal and bearing wear; for a journal having good resistance to wear may cause heavy bearing wear. The importance of the relative amount of wear that can be accepted by each component can only be determined by a cost analysis of bearing and shaft replacements for each class of vessels.

The data presented are from a limited number of tests under one set of conditions and are not to be considered as final. The wear characteristics of the individual materials may be revised as additional data become available.

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E. E. S. REPORT 9A066838
~~NS-633-001~~

U. S. NAVAL ENGINEERING EXPERIMENT STATION

Annapolis, Maryland

~~No 1179~~

abstract

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~~PROGRESS REPORT ON THE~~

WEAR CHARACTERISTICS OF STERN TUBE AND STRUT BEARING AND JOURNAL MATERIALS,

format 14 NAVENGRXSTA-9AΦ66838

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INTRODUCTION

1. The recent design changes in propeller shafting to utilize the increased strength of special alloy steels have necessitated a re-evaluation of the wear characteristics of the shaft sleeve and bearing materials. The greater shear and bending deflections of the new, smaller section modulus, shafts require a sleeve material having greater strength than the conventional cast bronze. Two alternative solutions are: (a) continue to use shaft sleeves, but of higher strength material, or (b) use a stainless steel shaft without sleeves in the way of the bearing.

2. This Station is currently engaged in the determination of sea water corrosion, vibratory cavitation and physical properties of a variety of propeller shaft journal materials. Unfortunately the results of the above tests cannot be interpreted at the present time to give an indication of the relative wear resistance of the materials. Each combination of journal and bearing materials must be tested under the conditions of the intended application. Thus, any test of journal materials is equally important for the evaluation of the bearing materials.

3. This report presents the results of wear tests of combinations of nine journal and four bearing materials when subjected to sand contaminated water lubrication. The tests were performed on a modified Amsler wear test machine and the conditions were arbitrarily chosen, i.e., shaft surface speed, bearing load, abrasive feed rate, elapsed time of test, etc. These conditions were maintained throughout this first series of 45 tests. It is well known that wear test data are inherently difficult to reproduce. A series of tests of one combination of materials would produce a range or band of results that would indicate the probable amount of wear to be expected under a certain set of conditions. The results reported are for one, or in some cases, two tests of each combination of bearing and journal materials, and therefore can be considered only as a preliminary indication of their wear resistance.

MATERIALS TESTED

4. Of the eleven propeller shaft journal materials to be tested under this program, the first nine listed below have been tested against each four bearing materials.

(a) Bronze, aluminum forgings, per N. D. Specification 46B33 (Ampco 45).

(b) Bronze, aluminum castings, per N.D. Specification 46B18, Class 3 (Ampco 16).

(c) Copper-nickel alloy centrifugal castings, 80% copper and 20% nickel.

(d) Metal, gun castings, per N.D. Specification 46M6, Comp. G.

(e) Bronze, valve castings, per N.D. Specification 46B8, Comp. M.

(f) Brass, naval wrought, per Specification MIL-B-994, Comp. A, half hard bars.

(g) Nickel-copper alloy, per Specification MIL-N-894, Class A, cold drawn bars (monel).

(h) Nickel-copper alloy, per N.D. Specification 46N5, cold drawn rods, heat treated (K monel).

(i) Steel, corrosion resisting, Type 322, (stainless W) precipitation hardened to approximately 43 Rockwell C.

(j) Steel, corrosion resisting, precipitation hardening (Armco 17-4 PH).

(k) Steel, corrosion resisting per Specification MIL-S-853, Class 3, (410 stainless).

The nominal composition, Rockwell hardness, and specimen diameter for each material are given in Plate 1.

5. The materials used for bearings in this program are as follows:

(a) Synthetic rubber, per N.D. Specification 33B5, Class 2 (Buna-N, .77 Durometer hardness).

(b) Phenolic resin impregnated, laminated, cotton cloth, per N.D. Specification 33B4, Type A, edge of laminations presented to wearing disc (Micarta grade 223).

(c) Phenolic resin impregnated, laminated, cotton cloth, per N.D. Specification, Type B, flat of laminations presented to wearing disc (Ryertex grade BE).

(d) Lignum Vitae wood, per N.D. Specification 39L2, end of grain presented to wearing disc.

TEST EQUIPMENT

6. One of the more widely known wear testing machines is manufactured by A. J. Amsler, Schaffhouse, Switzerland. Since the machine was available at the Station, modification of the machine appeared more promising than to design and build a separate testing machine.

7. Preliminary tests indicated that an abrasive (sand) feeding mechanism was required to deliver a metered amount of sand to the wearing surfaces. The addition of an endless belt conveyor, fed from a hopper, and driven by a synchronous timing motor, produced the desired conditions. The vertical adjustment of the hopper opening above the belt varies the height, and thus the weight per unit time, of the abrasive moving on the belt. The dry abrasive is dropped free from the end of the belt, down a chute, and onto the top of the rotating journal specimen.

8. A new bearing support was fabricated to maintain line contact between the bearing and journal specimens with an integral lever arm to apply load to the specimens. The support is bolted to the machine bed plate incorporating a sheet spring steel hinge to permit movement of the support, but to maintain the bearing face parallel to the axis of rotating journal disc. Plate 7 indicates the relative position of specimens, abrasive chute and loading arm.

9. The water for lubrication is admitted through a nozzle having a narrow opening the width of the journal specimen. It is located on the horizontal center line of the journal, 90° ahead of the sand chute outlet, and 180° ahead of the bearing. The film of water carried by the journal picks up the falling particles of sand and wets them before reaching the contacting surfaces. Excess water, not carried around with the journal, washes off the sand having passed through the bearing. This prevents the wear products from the bearing and journal from being returned to the wearing surfaces and complicating the test.

10. To measure the wear of journal and bearing (combined) during each test, a dial indicator is used. It is mounted on the machine frame with the stem touching the bearing support on the horizontal center line of the journal and the line of contact extended. Plate 5 is a general view of the test equipment.

TEST SPECIMENS

11. The bearing specimens were obtained from stern tube and strut bearing staves that had previously been submitted to this Station for type and brand approval testing. The materials had all passed the requirements of their respective specifications. The specimens were milled to nominal 1-inch cubes, with the exception that the rubber staves were only 3/4-inch thick. Following machining, the test faces of the phenolic and wood specimens were lapped by hand on 1/0 and 3/0 emery polishing paper until all traces of lint had disappeared from the surfaces. Rubber specimens were finished by grinding.

12. The bearing specimens were tested without any controlled conditioning to specific moisture content conditions. The rubber and plastic specimens had been stored dry at room temperature, and were kept dry until the test run began. Tl e Lignum Vitae wood, however, had been stored submerged in water. The material was removed from the water only as necessary to machine the bearing cubes, measure, and test. No cracks, checks, or shakes were visible in the finished wood specimens.

13. Preliminary tests were made with 2-5/8-inch diameter by 1/2-inch wide journals having a 1/8-inch radius on the outside edge. (See Plate 6, section BB). The specimen shape was altered to a flat disc as being more representative of an actual bearing surface (See Plate 6, section AA). The later type was used for all tests herein reported. The discs were originally machined 2 to 3-inches in diameter, depending upon the stock supplied. Only a limited number of specimens of each material was available, requiring refinishing and re-use of the discs. Prior to test, all journal specimens were precision measured over two diameters, 90° apart, and over the width of the discs in four places, 90° apart. Specimens were numbered and marked to indicate the location of measurement points.

ABRASIVE

14. The sand abrasive was obtained from the beach of the Severn River adjacent to the Station. The individual particles have rounded edges and are considered to be typical of the abrasive encountered in shipboard bearings. The material was thoroughly washed, dried, and screened before use. Preliminary tests indicated that when using a mixture of particle sizes, the largest particles would jam into the bearing and pass all the fines. The size of specimens prevented effectual use of all large particles (approx. 20 mesh), because the bearing

would jump away from the journal to pass the particles, causing a vibrational effect. The use of all fines (smaller than 70 mesh) resulted in a slow wear rate and some flotation of the particles on the film of water carried on the journal.

15. The sand was screened with U.S. Standard sieves and only that fraction passing the No. 40 and remaining on the No. 50 was used. This material was a compromise between the larger and smaller sizes and yet of fairly uniform size. The openings of the 40 and 50 mesh sieves are 0.0165 and 0.0117 inch, respectively, resulting in particle sizes averaging approximately 0.0141 inch in thickness.

LUBRICANT

16. The lubricant supplied to the test specimens was Station tap water at approximately 70°F, the temperature being variable from day to day. The flow was adjusted by a hand operated needle valve to produce a film on the journal plus a small excess, not carried in the direction of rotation, to wash the used sand from the journal.

METHOD OF TEST

17. The prepared journal and bearing specimens were secured to the drive spindle and support respectively and the proper weight attached to the lever arm to produce a load of 4 pounds per inch of width of journal. It was recognized that the change in journal specimen diameter from 2 to 3 inches would reduce the original contact (Hertz) stress. However, as soon as any wear occurred, the area of contact would considerably reduce the contact stress, and the load per unit width, regardless of wear, would be a better basis for comparison. The bearing specimen being the wider of the two, was centered horizontally and vertically to insure that the final wear pattern would not extend to an edge of the cube. The machine was started and adjusted to the correct rpm to produce a journal surface speed of 100 feet per minute. The water lubricant was turned on and adjusted.

18. With the use of a stop clock, the sand abrasive feed system was started and at the same time the bearing was permitted to contact the journal under load. After each 5 minutes of the 1-hour test, the bearing was retracted from the journal and the other components stopped to permit cleaning of the contacting surfaces and the measuring of the combined wear of journal and bearing. A dial indicator having 0.0001 inch graduations was bolted to the machine with its stem retracted during the running periods. To obtain a measurement, the stem was released

and it contacted the bearing support arm on an estension of the line of contact of the specimens. The journal was rotated to the same indexed position prior to each measurement. The clearance in the ball bearings supporting the spindle was assumed to be removed each time by the contact load. The sand, fed at a rate of approximately 32 grams per hour, was collected at the lubricant drain, and was not re-used.

19. Data recorded included the following:

(a) Weight of journal before and after test.

(b) Weight of sand passed through bearing.

(c) Combined wear of specimens after each 5 minute run.

(d) Check of shaft rpm during test.

(e) Measurement of the maximum depth of the final wear pattern in each bearing. (End of measuring spindle having a 1/8-inch radius spherical surface)

(f) Diametral measurement of each journal before and after test.

(g) Hardness of each journal material.

20. Each of the nine journal materials were tested against each of the four bearing materials. In addition, a replication was made of all the journal-Micarta tests. Within the time available, it was not possible to re-run all tests nor to explore the effects of the possible variables on the wear characteristics of one combination of materials. An attempt was made to arrange the tests in a statistical pattern so that when a sufficient number of tests have been completed, a thorough analysis can be made. However, tests were initiated when only a few of the several journal materials were available. As each additional material was procured and specimens machined, the testing sequence was amended. As a result the pattern of tests are in four small groups rather than one large group.

RESULTS OF TESTS

21. The losses in weight of the journal specimens are presented in Plate 2. The arrangement of the metals in the order of their decreasing resistance to wear, as averaged from the tests against the four bearings, is as follows:

		Wt. Loss 10^{-3} Grams
K Monel - best	-	26.1
Monel	-	33.3
Composition M	-	36.1
Composition G	-	37.5
Stainless W	-	41.0
80-20 copper-nickel	-	50.3
Aluminum bronze, Ampco 16	-	61.8
Aluminum bronze, Ampco 45	-	89.0
Compositon A - poorest	-	92.4

Similarly, the arrangement of the bearing materials in the order of their decreasing effect on the average wear of the journals is as follows:

		Wt. Loss 10^{-3} Grams
Synthetic Rubber (Buna-N) least journal wear	-	21.0
Lignum Vitae wood	-	37.2
Phenolic impregnated laminate (Ryertex)	-	66.3
Phenolic impregnated laminate (Micarta) - most journal wear	-	77.2

22. The results of the tests which indicate the wear of the bearing materials are presented in Plate 3. Part A is the tabulation of the measured depth of the wear pattern after completion of the test run. It is an indication of the maximum depth in the pattern as probed with a rod having a 1/8-inch radius spherical end. Part B is the tabulation of the minimum depth, as determined by recording the relative movement of the specimens from the original or no-wear position. While the latter is the amount of the combined wear of journal and bearing, the dimensional change of the journals is negligible compared with the bearings. The wear resistance of the bearing materials as averaged for all journals is as follows:

Part A

		Wear 10^{-3} In.
Buna N	-	neg.
Micarta	$\frac{19.8 + 23.1}{2}$	= 21.5
Ryertex	-	22.2
Lignum Vitae	-	22.5

Part B

		Wear 10^{-3} In.
Buna N	-	neg.
Lignum Vitae	-	6.7
Ryertex	-	10.3
Micarta	$\frac{10.7 + 11.5}{2}$	= 11.1

23. The difference in the wear of the bearings, as shown in Parts A and B of the table, is easily explained. The depth of the wear is usually not uniform across the width of the pattern, in many cases a series of ridges and valleys. The high points actually support the journal during the "B" measurement, while the probe approaches the bottom of the valleys during the "A" measurements. The difference between the two approximates the average thickness of the sand particles, when the "A" values are greater than 0.025-inch. As the depth of wear decreases, the difference between the two values decreases. The "B" values have been used in the interpretation of the data, as being more representative of an actual bearing application.

24. The effect of the journal material on the wear of the bearing is reflected by averaging the depths of wear for the three bearings (synthetic rubber being negligible). The order of resistance to bearing wear produced by the journals is as follows:

Part A	Wear 10^{-3} In.	Part B	Wear 10^{-3} In.
Ampco 16	- 3.0	Ampco 16	- 1.2
Ampco 45	- 4.3	Ampco 45	- 1.6
Comp. A	- 13.0	Comp. A	- 4.5
Comp. G	- 25.8	Comp. G	- 7.0
K Monel	- 26.5	Stainless W	- 11.3
Monel	- 26.7	Monel	- 11.6
Stainless W	- 28.0	K Monel	- 13.0
Comp. M	- 32.8	Comp. M	- 13.8
80-20 Copper-nickel	- 38.5	80-20 Copper-nickel	20.5

In each case the average of the two Micarta tests was combined with the Lignum Vitae and Ryertex tests to compute the wear for each journal material. The data obtained by stopping the tests each 5 minutes and recording the progressive wear of the combination was plotted on both coordinate and semi-logarithmic graph paper. An attempt was made to determine the relative rates of wear of the bearing materials. The plots on coordinate paper usually indicated high rates of wear early in the test, the rate decreasing with an increase in time. The semi-logarithmic plots were not too satisfactory, particularly during the first 30 minutes of the tests. Semi-logarithmic plots of the data taken during the last 30 minutes (seven points) tended to form straight lines for four of the nine journal materials for each of the three bearing materials. The slopes of these lines should indicate their relative tendency to produce bearing wear. The materials lined up as follows:

		Slope Indication
Ampco 16 - best	-	5.5
Ampco 45	-	7.5
Comp. M	-	14.5
Comp. A - poorest	-	21.3

The preceding data presentations indicate the relative resistances of the journal materials with respect to journal wear and to producing bearing wear without bringing them together. They do not answer the primary question, "What is the best journal for the least combined wear?" Plate 7 represents an attempt to provide a method of data presentation which enables a weighted evaluation of the combined journal wear properties. Plate 7 has been constructed so that the range from best to poorest material, in each case, has been given the same length of vertical scale. The individual materials are then plotted to their same relative positions along the scales; the best material, considering bearing wear, being at the top of one scale; and the best, considering journal wear, being at the top of the other scale. Lines connecting the two points for each material can thus be used for further evaluation, depending upon the qualities desired. Line AA on Plate No. 7 is designated as the "relative importance" line, and has arbitrarily been located between the two scales.

25. Stern tube and strut bearing design has been based on the desire to have the wear occur on the bearing and not on the shaft sleeve. However, some wear takes place on both; and it is the "relative importance" of the two amounts of wear that should be considered. The position of line AA can only be determined by choosing the relative amount of wear that can be permitted on the journal and bearing. Moving the line towards the right would give an indication of materials to use to produce the lesser amount of wear on the journal. Conversely, moving the line to the left produces similar data with respect to wear on the bearing. The intersection of the individual material lines with AA, as located and from top to bottom, would have 75% of the qualities of journal wear and 25% of the qualities of bearing wear. The order of the materials at 25, 50, and 75% of the journal properties are as follows:

25%	50%	75%
Ampco 16	Comp. G	K Monel
Ampco 45	Ampco 16	Comp. G
Comp. G	K Monel	Monel
Comp. A	Monel	Comp. M
Monel	Stainless W	Stainless W
Stainless W	Comp. M	Ampco 16
K Monel	Ampco 45	80-20 Cu Ni
Comp. M	Comp. A	Ampco 45
80-20 Cu Ni	80-20 Cu Ni	Comp. A

Previous experience and desires may properly place line AA to the right of the 50% position, but for the present only judgment, not proof, is available. The position of the line, and thus the relative order of the journal materials, is obtainable only through practical long term tests aboard ship, together with a complete analysis of the cost of bearing and sleeve replacements. Only then can a correlation be made between laboratory and service testing.

26. Using the same approach to the evaluation of the bearing materials, Plate 8 shows that there is no need for a "relative importance" line. For the 4 materials tested, data presented in paragraphs 20 and 21, the effect of the bearing material on the resulting wear of the bearings and journals is in the following same order:

Buna N - best
Lignum Vitae
Ryertex
Micarta - poorest

These values are obtained from the average of the tests against all nine journal materials. It should be pointed out that although the scales of Plates 7 and 8 are marked from good to poor, it does not mean that the materials near the bottom of the scales are, in actual practice, poor. The materials tested are only a small fraction of the total number possible, and it does not intend to show what is, or is not, an acceptable wear value.

APPEARANCE OF SPECIMENS

27. Journals - The surfaces of the journal specimens, following the tests, had the following three classes of wear appearance:

(a) Grooving and upsetting, shiny and uniform about the periphery.

(b) Pockmarked or sand-blasted as though abrasive particles were forced into the surface.

(c) Smearing or tearing of the surface as though lathe turned with a dull tool.

28. In general, the journals run against synthetic rubber had appearance (a). The remaining tests were characteristic of the journal, not the bearing as follows:

Composition G	-	80% (b) and 20% (c)
Ampco 45	-	100% (a)
Composition M	-	80% (b) and 20% (c)
80-20 Copper-Nickel	-	80% (b) and 20% (c)
Composition A	-	20% (b) and 80% (c)
Stainless W	-	10% (b) and 90% (c)
Monel	-	25% (b) and 75% (c)
K Monel	-	30% (b) and 70% (c)
Ampco 16	-	95% (a) and 5% (c)

29. Bearings - The surfaces of the synthetic rubber bearing specimens were given a slight polish by the tests, but there was no appreciable amount of wear. The remaining specimens were worn to varying depths, the leading edge wear being uniform across the width of the pattern, but ridges and valleys forming towards the trailing edge. There was no observable relationship between either journal or bearing material on the formation of the ridges. The inherent non-uniformity of the wood and laminated plastic material may be the basis for areas of greater wear resistance. Further, the abrasive particles may follow paths of least resistance as they pass through the bearing, with more and more alignment as they reach the trailing edge.

DISCUSSION OF RESULTS

30. In this series of tests, the attempt was made to reduce the many variables of the problem to the wear of bearings and journals only. In practice, this cannot and was not fully achieved. The following items will be mentioned as some of the larger variable factors that may have had some effect on the results:

(a) Variation in specimen diameter - The specimens of five materials were nominally 2-inches in diameter, while the remaining specimens were nominally 3-inches in diameter. The surface speeds of the journals were kept constant (±2 rpm) but with the change in diameter, the wear pattern depth to length ratio would change. From the results plotted on Plate 7 however, there does not appear to be any trend in favor of one size or the other; both sizes being well distributed on the scales.

(b) Variation in journal surface finish - The specimens were lathe turned and not ground or polished, which may have had an effect on the wear rates during the first few minutes of the tests. However, such effect, if any, is not considered important, because the original surface was quickly changed by the sand abrasive and assumed a new surface, characteristic of the material.

(c) Variation in sand feed rate - The sand fed through the bearing was collected and weighed following each test. The variation between tests was not over ± 10% with the exception of the Stainless W tests. These tests, run last in the series, had approximately 20% more sand delivered to the bearing than the average. Further tests would indicate the effect of sand rate on the wear of the materials.

(d) Wet and dry bearing specimens - The use of the materials in the "as is" condition, without long periods of conditioning prior to test, prevented the use of all dry or all soaked specimens. The Lignum Vitae wood was submerged in water except for short periods when the pieces were being machined, etc. The laminated plastic and the rubber materials were maintained at room conditions, and the wearing surfaces were wet only during the test period. This procedure is normally used, however, in the fleet; the Lignum Vitae being wet, and the rubber and plastics dry before installation. Again, only further testing will indicate the effect of specimen moisture content on wear resistance.

31. The data are presented as averages for a particular bearing or journal material, rather than discussing each of the 36 combinations. Thus, Plate 7 shows the relative wear characteristics of each journal as averaged for all four bearings. This method was used because, regardless of which journal material may be selected, all four bearing materials are in use in the fleet and each type may at some time be inserted as a replacement. Moreover, in view of the small number of tests of any one combination of materials, the average values are considered to be indications of the relative wear properties rather than comparisons of the individual test results.

32. The weight loss of the journals has been used as the basis for wear rather than a change of diameter, even though the latter measurements were taken. The small weight losses were readily measurable, but this was not so with respect to the dimensional change; the largest weight loss recorded was computed to be equivalent to less than 0.0001-inch change in diameter. In addition, the final diameter of some specimens was found to be greater than the original, even though some metal was lost. This was caused by plowing and upsetting of the original surface by the abrasive.

33. It cannot be over emphasized that this data is preliminary, and may be revised as additional information becomes available. Changing any one of the conditions of the test, i.e., load, speed, abrasive rate

and particle size, conditioning of specimens, duration of test, etc., will change the wear rates of the materials and may change their relative resistance to wear. After the effects of each variable are investigated, it may then be possible to correlate the data from small tests with fleet replacement information.

CONCLUSIONS

34. The results of this preliminary investigation indicate the following:

(a) The test apparatus operated satisfactorily and produced data from which the relative wear characteristics of bearings and journals could be determined for a particular set of conditions.

(b) No one journal material can be considered the "best" for all stern tube and strut bearing applications. The wear of both journal and bearing wear must be considered, together with the relative importance of the wear being assumed by one or the other of the components.

(c) In general, a journal material showing good wear resistance has an adverse effect on the bearing wear; and vice versa.

(d) For the tests made, synthetic rubber (Buna-N) has the best average resistance to wear.

(e) Wear, as a mechanical property, is not a specific value, but rather a statistical average for a particular set of conditions.

RECOMMENDATIONS

35. It is recommended that the program be continued in accordance with the following additional objectives:

(a) Effect of surface speed of journal.

(b) Effect of abrasive feed rate.

(c) Reproducibility of test data by replication.

(d) Determination of rate of wear information by tests of longer duration.

(e) Effect of conditioning of bearing specimens.

(f) Evaluation of friction data obtained during future tests.

NOMINAL DIAMETERS, HARDNESSES AND COMPOSITIONS OF JOURNAL MATERIALS

Material	Nominal Outside Dia.	Rockwell Hardness	Composition - %									
			Cu	Sn	Pb	Zn	Ni	Fe	Mn	Al	Cr	Ti
Composition "M" Bronze	2	B-22	87	6	1.5	4	1	.25				
Aluminum Bronze (Ampco 16)	2	B-80	86.6				.2	3.3	.02	9.9		
Aluminum Bronze (Ampco 45)	2	B-99	81.7				4.7	2.8	.75	9.9		
80-20 Copper Nickel	2	B-87										
Cast Monel	3	B-82	30				67	1.5	1			
K Monel	2	C-20					66			3.		
Gun Casting Metal (Comp. G)	3	F-31 to B-17	86	8	.3	4	1	.15				
Naval Wrought Brass (Comp.A)	3	B-54	61	.75	.1	38		.1				
Stainless Steel (W)	3	C-44					7			.5	17	1

WEIGHT LOSS (WEAR) OF JOURNALS - GRAMS

Material	Comp M	80-20 Cu-Ni	Ampco 16	Ampco 45	Comp G	K Monel	Monel	Comp A	Stain "W" (322)	Avg
Micarta	.065	.122	.094	.114	.051	.023	.046	.146	.034	.077
Ryertex	.057	.054	.073	.100	.041	.043	.038	.114	.077	.066
Lig. Vitae	.012	.012	.059	.092	.027	.013	.012	.095	.013	.037
Buna "N"	.009	.018	.021	.035	.025	.006	.029	.021	.025	.021
Micarta*	.068	.112	.094	.144	.063	.062	.062	.133	.064	.089
Avg	.036	.050	.062	.089	.038	.026	.033	.092	.041	

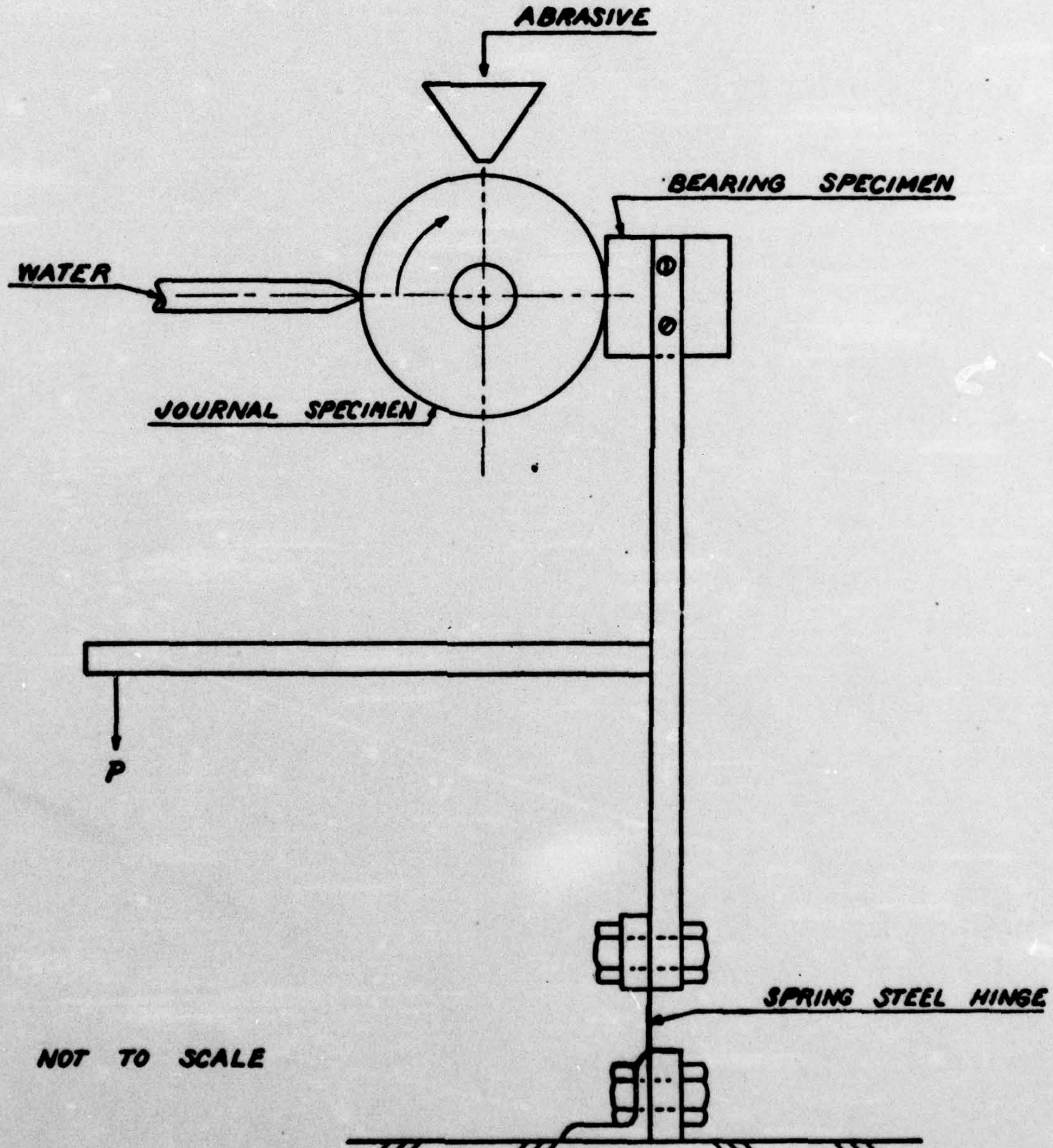
*Second Test

WEAR RATES

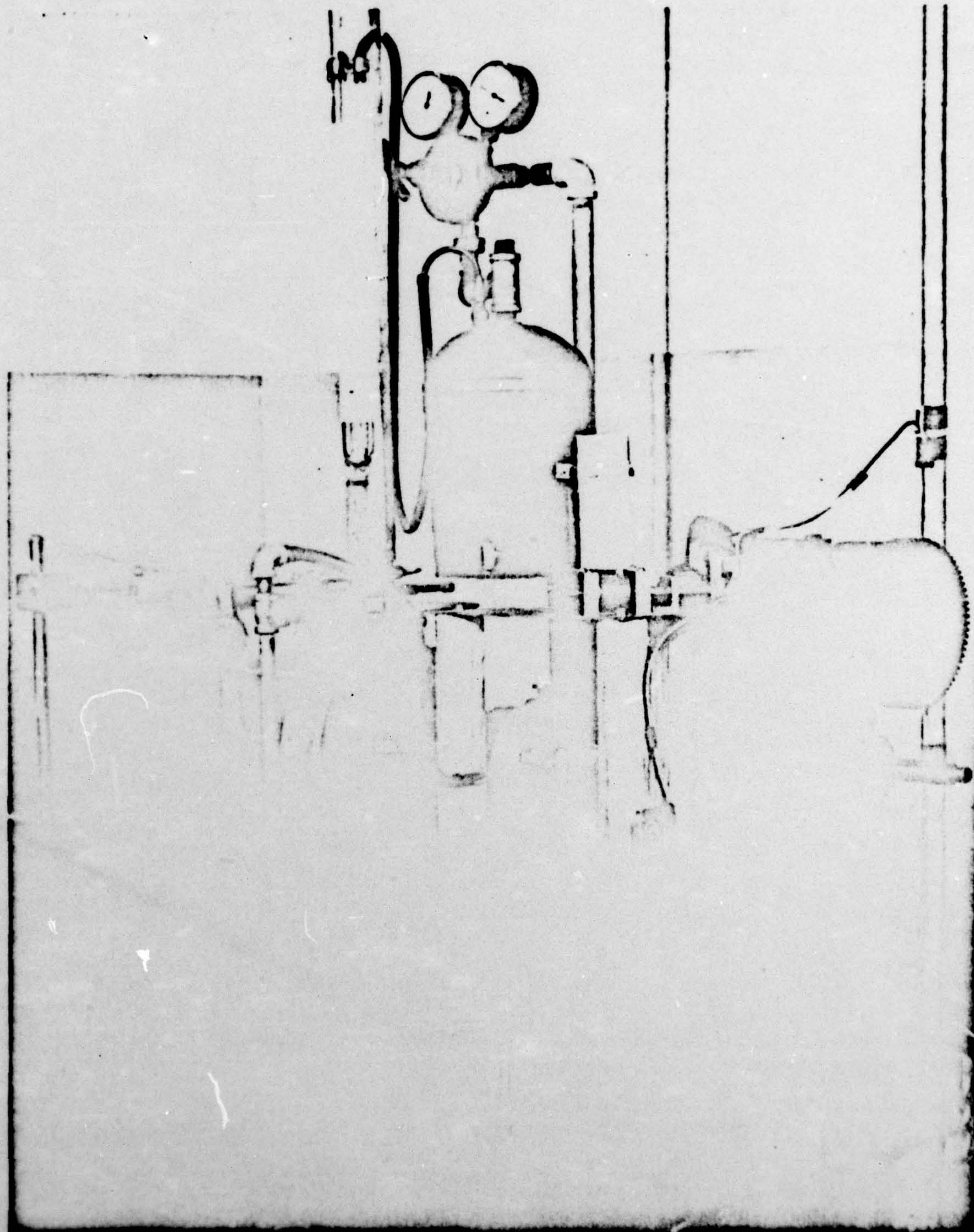
Bearing Material	Journal Material: Comp M	80-20 Cu-Ni	Ampco 16	Ampco 45	Comp G	K Monel	Monel	Comp A	Stain "W" (322)	Avg
A. Depth of wear in bearing materials - 10^{-3} inches (maximum depth to bottom of wear pattern valleys)										
Micarta	33	53	5	4	24	11	18	16	14	19.8
Ryertex	33	36	1	2	30	28	31	13	26	22.2
Lig. Vitae	33	34	3	5	23	30	30	9	36	22.5
Buna N	N	1/2	N	N	N	N	N	N	N	N
Micarta*	32	38	5	8	25	32	20	18	30	23.1
Avg	32.8	38.5	3.0	4.3	25.8	26.5	26.7	13.0	28.0	
B. Combined wear of journal and bearing materials - 10^{-3} inches (minimum depth to tops of wear pattern ridges)										
Micarta	14.4	39.2	1.9	1.5	6.0	10.3	12.0	4.0	7.0	10.7
Ryertex	15.6	16.7	1.0	0.7	10.5	15.3	13.3	6.7	13.0	10.3
Lig. Vitae	11.7	12.4	N	N	4.1	9.3	9.0	2.5	11.3	6.7
Buna N	N	N	N	N	N	N	N	N	N	N
Micarta*	13.8	25.3	3.2	6.4	6.8	18.4	12.8	4.7	12.2	11.5
Avg	13.8	20.5	1.2	1.6	7.0	13.0	11.6	4.5	11.3	

* Second Test

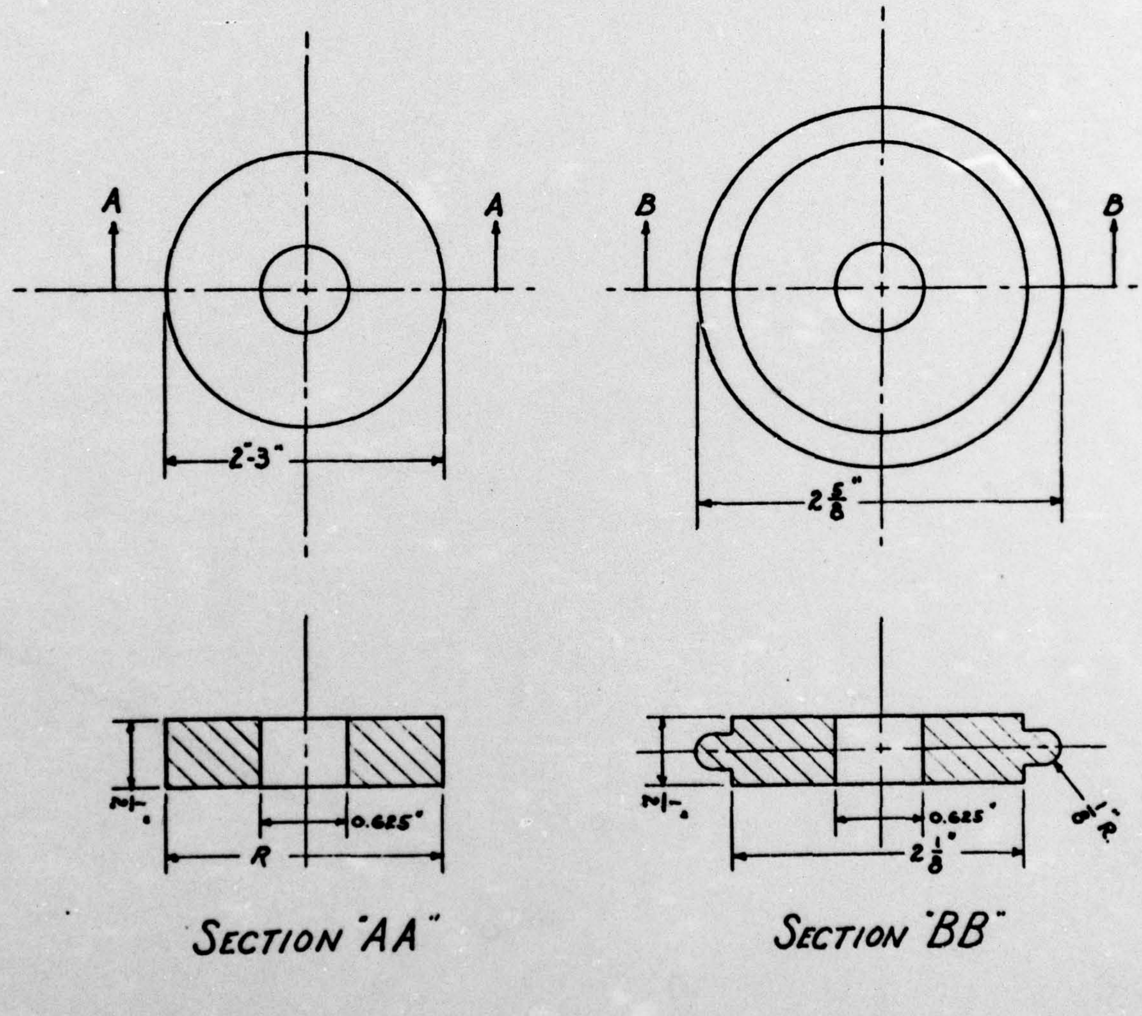
DIAGRAM OF EQUIPMENT ARRANGEMENT



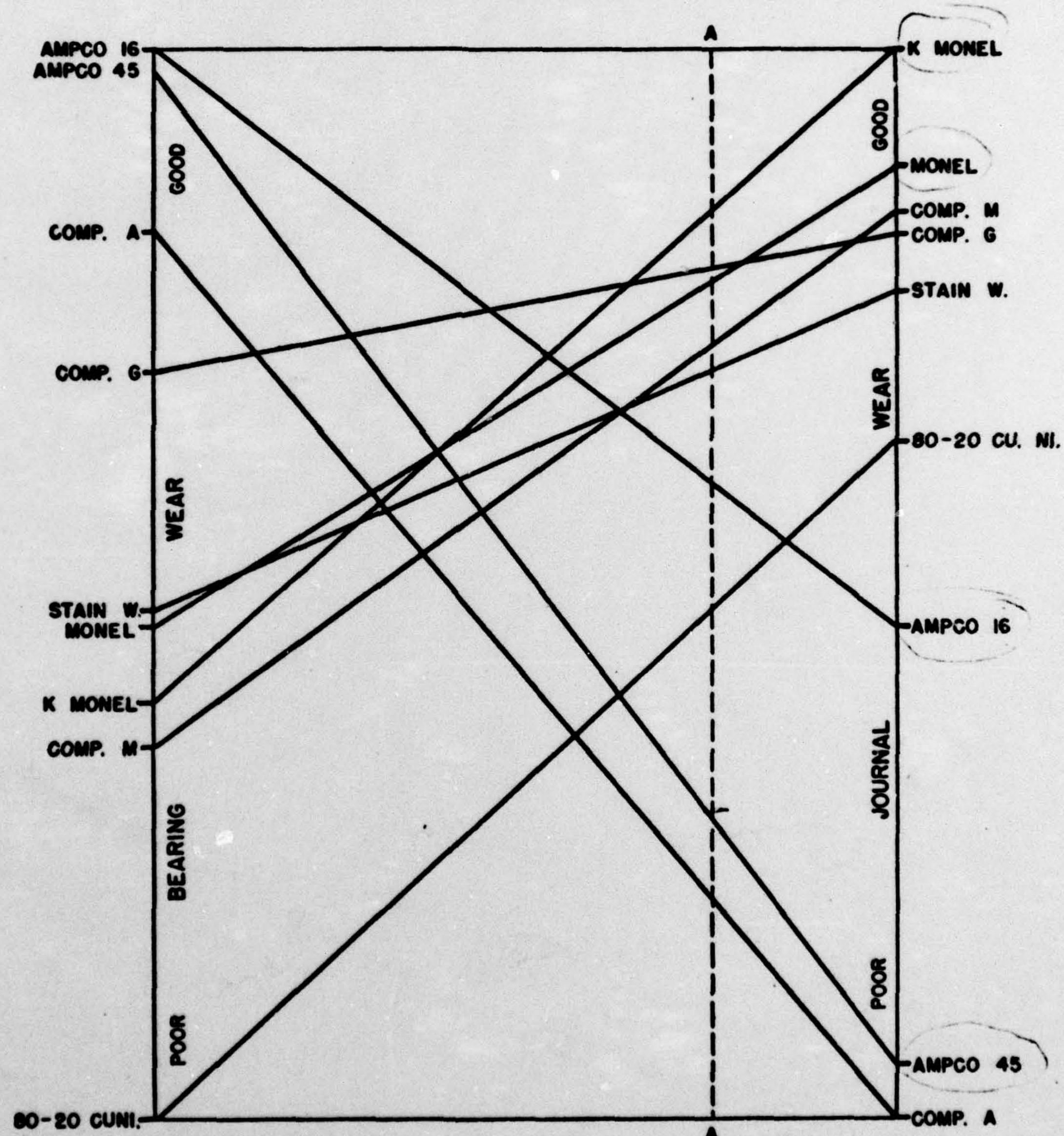
GENERAL VIEW OF TEST EQUIPMENT



NOMINAL DIMENSIONS OF JOURNAL SPECIMENS



RELATIVE WEAR OF JOURNALS AND BEARINGS
AS AFFECTED BY THE MATERIAL OF THE JOURNALS



RELATIVE WEAR OF JOURNALS AND BEARINGS
AS AFFECTED BY THE MATERIAL OF THE BEARINGS